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A method of averaging frequency modulated signals

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(EL-37)

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A METHOD OF AVERAGING FREQUENCY MODULATED SIGNALS

SUMMARY

This report describes a method of averaging two frequency modulated carriers in such a way that the resultant signal has a deviation equal to the average deviation of the two input frequencies. This technique has been applied successfully to the Research Department Field Store Standards Converters which require that interpolation should, if possible, be carried out, on an RF carrier, frequency modulated by television signals. A novel form of frequency adder is used as the basis of the system.

Also indicated are the precautions required to ensure that the system introduces no spurious frequency modulation that would be perceptible on the output picture.

1. INTRODUCTION

Frequency modulation of video information is used in the field store standards converter[1] in order to reduce the effects of gain inequalities in the delays.[2] However, interpolation[3] requires the weighted addition of successive field lines or successive picture lines. Demodulation of the f.m. signal and subsequent re-modulation, in order to carry out a simple addition of the video signals is possible, but this has disadvantages. It would be difficult to achieve the required degree of matching in the modulators and this would give rise to objectionable patterning when switching between sources with unequal modulator/demodulator characteristics.

This report describes a system of averaging two frequency modulated video signals which does not require demodulation and subsequent re-modulation.

2. THE AVERAGING PROCESS

The averaging device is required to be capable of averaging two instantaneous frequencies lying in the range of deviation of the f.m. system employed. This range is from 31·5 to 32·5 MHz in the example described in this report.

The simplest way of averaging two f.m. signals (f_1 and f_2) is to multiply them to produce their sum ($f_1 + f_2$) and then divide this new frequency by two to obtain the average

$$\left(\frac{f_1 + f_2}{2}\right).$$

Since the two frequencies are close, however, a multiplier that produces harmonics (a bridge ring-modulator, for example) is unsuitable as the second harmonics of the input frequencies would be inseparable from the required sum frequency.

A device that produces half-sum and half-difference frequencies *only* can be made simply by adding the two signals (A at f_1 and B at f_2) at the *same* amplitude, the result of which is a frequency

$$\left(\frac{f_1 + f_2}{2}\right)$$

amplitude-modulated at a frequency

$$\left(\frac{f_1 - f_2}{2}\right)$$

as can be seen in Fig. 1(*a*).

This is shown in the trigonometric identity:

$$E\sin\omega_1 t + E\sin\omega_2 t = 2E\sin\frac{(\omega_1 + \omega_2)t}{2}\cos\frac{(\omega_1 - \omega_2)t}{2}$$

Similarly, if the signals A and B are subtracted, the same frequencies result but they are in quadrature with the corresponding frequencies from the addition, as shown in the identity:

$$E\sin\omega_1 t - E\sin\omega_2 t = 2E\cos\frac{(\omega_1 + \omega_2)t}{2}\sin\frac{(\omega_1 - \omega_2)t}{2}$$

In both cases the wanted

$$\left(\frac{f_1 + f_2}{2}\right)$$

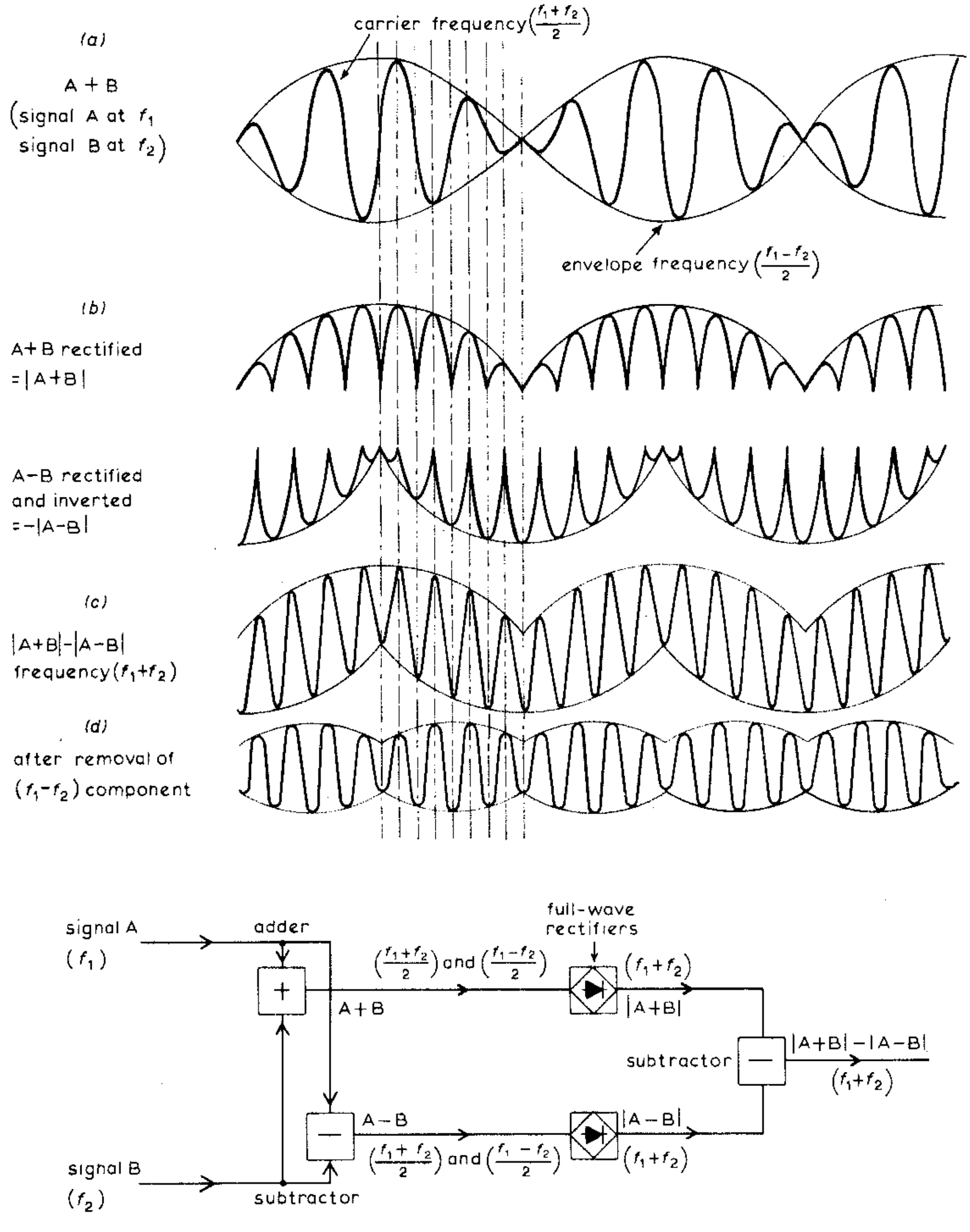

Fig. 1 - Waveforms at stages throughout mixing process

component suffers a phase reversal at every zero-crossing of the

$$\left(\frac{f_1 - f_2}{2}\right)$$

component (see Fig. 1(*a*)), but full-wave rectification may be employed to remove this – a process that also doubles the fundamental frequency, producing $(f_1 + f_2)$ (Fig. 1(*b*)).

Although the signals after rectification are of continuous phase they are still heavily amplitude modulated. However, the $(f_1 + f_2)$ component resulting from the subtraction of the signals is now in anti-phase to that from the addition, so that if the two rectified waveforms $|A + B|$ and $|A - B|$ are subtracted, the wanted $(f_1 + f_2)$ frequency remains – with most of the amplitude modulation removed (Fig. 1(*c*)).

Unwanted frequency components introduced in the rectification stages can be filtered out and the remaining amplitude modulation is easily removed by a limiter (Fig. 1(*d*)).

It is shown in the Appendix that the generation of harmonics and side-bands, although giving rise to amplitude modulation, does not generate unwanted frequency modulation.

3. THE CIRCUITS

Fig. 2 shows the complete averaging system and indicates the separate, screened units in which the different stages were isolated.

The mixer described in Section 2 produces the sum of the two input frequencies and thus the complete averaging process involves the use of divide-by-two stages. These are placed before, rather than after, the mixer since the divider circuits act conveniently as limiters which stabilise the amplitude of the mixer inputs and mixing is easier at lower frequencies where stray reactive effects are less important.

Since the divide-by-two process produces many unwanted harmonics, a filter is required to separate the 16 MHz components and the associated sidebands, extending from 10 MHz to 22 MHz. The filter cut-off must be sharp if the second harmonics are to be rejected, since these extend from about 26 MHz to to 38 MHz.

The frequency adder performs three distinct operations. Addition and subtraction of the two carriers, fullwave rectification, and finally subtraction. The addition and subtraction of the input signals to produce (A + B) and (A – B) is carried out in two transformers which feed signals of equal amplitude, from equal impedances, to the two rectifying stages.

The output of the adder is amplitude-modulated and any distortion that could convert amplitude variations into phase variations must be avoided, as these would give rise to spurious frequency modulation. If a filter with a sharp cut-off were used to filter the output of the adder, the higher a.m. sidebands (corresponding to the sharp cusps on the waveform) would be liable to phase distortion and this, in turn, would result in unwanted frequency modulation. A filter with a bandwidth of 25 – 39 MHz and a 'slow roll-off' characteristic is therefore used to remove the harmonics and the low-frequency component that are generated in the rectifiers.

It is also important that the final limiter should not introduce excessive phase distortion with varying signal amplitude. Back-to-back diode limiting stages were found to be satisfactory in this respect, although it was necessary to incorporate a trimmer capacitor in one of the stages to minimise phase-variation with amplitude and to compensate for similar distortion introduced in the mixer stage.

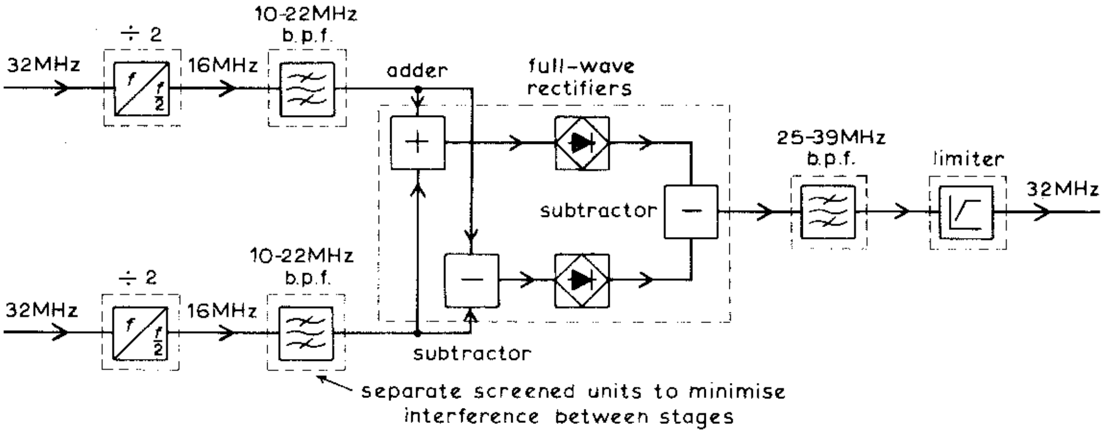

Fig. 2 - Complete averaging system

4. RESULTS AND PERFORMANCE

The system described in Sections 2 and 3 was initially tested by feeding c.w. signals into the divide-by-two units. Their frequencies were 31·5 MHz and 32·5 MHz and these represent, on the f.m. system employed, video levels of white and black respectively.

When the output of the limiter was demodulated, a d.c. level corresponding to the average frequency (32 MHz, i.e. mid-grey) was expected. However, spurious pulses, coincident with the cusps of the a.m. envelope (see Fig. 1(*d*)), were observed and it was deduced that a part of the system possessed a phase response that was amplitude-sensitive. The signal-dependent capacitance in the base/emitter junction of the rectifying transistors was found to be largely responsible for this. The effect was minimised by reducing the emitter current. The pulses were thus reduced in amplitude by 15 dB and the lowest spurious signal level achieved was 36 dB below the maximum signal amplitude.

As expected, the spurious pulses were reduced to a much lower level as the two input frequencies were brought closer together, indicating that if two picture signals of identical brightness were averaged, there would be no spurious signal.

In the field store standards converter, the signals to be averaged are successive television fields or lines and large differences between adjacent lines or fields occur only rarely. Spurious signals are therefore generally confined to small areas and are considerably lower in level than −36 dB.

Tests to determine the visibility of the spurious signals were carried out and it was found that if a picture signal (Test Card C) was averaged with a constant frequency representing black level, the pulses were visible as a moving dot pattern, the spacing of which depended upon the frequencies of the signals being averaged. The pattern became invisible when the pulse amplitude was below −28 dB relative to maximum signal level.

In practice, the only time that large spurious signals could occur would be when a white object moved over a black background (or vice versa) since on the edges of the object, areas of different luminance would overlap in successive fields.

Subjective tests with moving pictures were carried out using a field delay, the direct field being averaged with the delayed field. At no time, however, was it possible to detect any picture degradation which could be attributable to the averaging process.

5. CONCLUSIONS

The system described has been shown to be acceptable for the averaging of similar television picture lines.

Interference from spurious f.m. pulses is not a serious problem because the averaging of large frequency differences can only occur on the edges of moving objects where successive fields overlap. Under these conditions it has proved undetectable.

6. ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Mr. R.E. Davies whose theoretical work formed the basis for this development.

7. REFERENCES

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APPENDIX

The addition of two signals of equal amplitude, A at frequency $\frac{\omega_1}{2\pi}$ and B at frequency $\frac{\omega_2}{2\pi}$ is given by:

$$E\sin\omega_1 t + E\sin\omega_2 t = 2E\sin\left(\frac{\omega_1+\omega_2}{2}\right)t\,\cos\left(\frac{\omega_1-\omega_2}{2}\right)t$$

Similarly (A–B) is given by:

$$E\sin\omega_1 t - E\sin\omega_2 t = 2E\sin\left(\frac{\omega_1-\omega_2}{2}\right)t\,\cos\left(\frac{\omega_1+\omega_2}{2}\right)t$$

Let $\left(\frac{\omega_1+\omega_2}{2}\right)t = x_1$ (the high frequency component)

and $\left(\frac{\omega_1-\omega_2}{2}\right)t = x_2$ (the low frequency component)

and let $E = 1$v.

Thus, $(A+B) = 2\sin x_1 \cos x_2$

$(A-B) = 2\cos x_1 \sin x_2$.

If the (A+B) signal is rectified, the result is given by:

$$|A+B| = 2|\sin x_1 \cos x_2| = 2|\sin x_1| \times |\cos x_2| \qquad (1)$$

Similarly,

$$|A-B| = 2|\cos x_1 \sin x_2| = 2|\cos x_1| \times |\sin x_2| \qquad (2)$$

A rectified sinusoid may be expressed in the form of a fourier series, and by expanding $|\sin x_1|$ and $|\cos x_1|$, equations (1) and (2) may be re-written:

$$|A+B| =$$

$$= 2|\cos x_2| \times \frac{4}{\pi}\left[\frac{1}{2} - \frac{1}{3}\cos 2x_1 - \frac{1}{15}\cos 4x_1 - \frac{1}{35}\cos 6x_1 - \ldots\right]$$

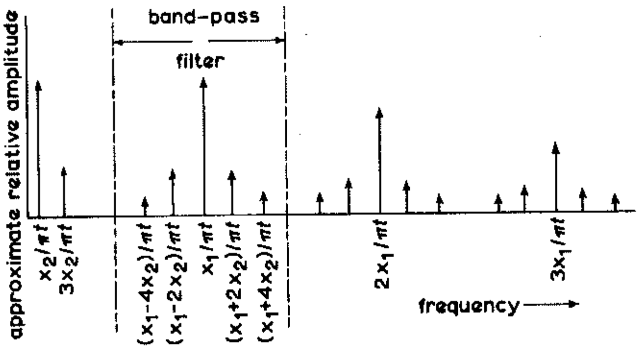

Fig. 3 - Spectral analysis of the averaged signal

$$|A-B| = 2|\sin x_2| \times \frac{4}{\pi}$$

$$\left[\frac{1}{2} + \frac{1}{3}\cos 2x_1 - \frac{1}{15}\cos 4x_1 + \frac{1}{35}\cos 6x_1 - \ldots\right]$$

However, the terms of frequency $4x_1$ and above will be filtered out by the 25 to 39 MHz band-pass filter. Ignoring these terms and expanding $|\cos x_2|$ and $|\sin x_2|$ these equations may be written:

$$|A+B| = \frac{8}{\pi}\left[\frac{1}{2} - \frac{1}{3}\cos 2x_1\right]$$

$$\times \frac{4}{\pi}\left[\frac{1}{2} + \frac{1}{3}\cos 2x_2 - \frac{1}{15}\cos 4x_2 + \ldots\right]$$

$$|A-B| = \frac{8}{\pi}\left[\frac{1}{2} + \frac{1}{3}\cos 2x_1\right]$$

$$\times \frac{4}{\pi}\left[\frac{1}{2} - \frac{1}{3}\cos 2x_2 - \frac{1}{15}\cos 4x_2 - \ldots\right]$$

Subtracting these two signals, as is done in the final stage of the mixer:

$$|A-B| - |A+B| = \frac{32}{\pi^2}\cos 2x_1$$

$$\left(\frac{1}{3} - \frac{2}{3\times 15}\cos 4x_2 - \frac{2}{3\times 63}\cos 8x_2 - \ldots\right)$$

$$-\frac{32}{\pi^2}\left(\frac{1}{3}\cos 2x_2 + \frac{1}{35}\cos 6x_2 + \ldots\right)$$

This expression includes terms at frequencies of $2x_2$, $6x_2$, $10x_2$, etc., which will be filtered out by the band pass filter and again may be ignored. Hence,

$$|A-B| - |A+B| =$$

$$= \frac{32}{3\pi^2}\left[\cos 2x_1 - \frac{2}{15}\cos(2x_1+4x_2) - \frac{2}{15}\cos(2x_1-4x_2)\right.$$

$$\left. - \frac{2}{63}\cos(2x_1+8x_2) - \frac{2}{63}\cos(2x_1-8x_2) - \ldots\right]$$

This expression represents a carrier frequency, $\frac{x_1}{\pi t}$, with symmetrical sideband frequencies spaced at multiples of $\frac{2x_2}{\pi t}$ on each side. This is the spectrum of an amplitude modulated signal which contains no frequency modulated components. The complete spectrum of frequencies produced in the mixer is shown in Fig. 3.